INCORPORATING CCSDS TELEMETRY STANDARDS AND PHILOSOPHY ON CASSINI

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Abstract

The Cassini project at the Jet Propulsion Laboratory (JPL) is implementing a spacecraft telemetry system based on the Consultative Committee for Space Data Systems (CCSDS) packet telemetry standards. Resolving the CCSDS concepts with a Ground Data System designed to handle time-division-multiplexed telemetry and also handling constraints unique to a deep-space planetary spacecraft (such as fixed downlink opportunities, small downlink rates and requirements for on-board data storage) have resulted in spacecraft and ground system design challenges. Solving these design challenges involved adapting and extending the CCSDS telemetry standards as well as changes to the spacecraft and ground system designs. The resulting spacecraft/ground system design is an example of how new ideas and philosophies can be incorporated into existing systems and design approaches without requiring significant rework. In addition, it shows that the CCSDS telemetry standards can be successfully applied to deep-space planetary spacecraft.

1.0 Introduction

In order to provide context, this section describes the Cassini Mission, Cassini Spacecraft, and Cassini Ground System.

1.1 Cassini Mission

The goal of the Cassini mission is to provide in-depth exploration of the Saturnian system. This includes the planet itself, the rings and magnetosphere, the moon Titan, and eight icy satellites. Launch of the Cassini spacecraft is set for October 1997. The trajectory to Saturn will take 6.7 years and require flybys of Venus and Earth for gravity assists. The trajectory also includes a Jupiter flyby. Arriving at Saturn in June 2004, the spacecraft will perform a Saturn Orbit Insertion (S01) maneuver and will orbit the planet for four years, until June 2008. This will provide a 60 orbit tour that includes 33 Titan flybys. During the first or second flyby, the Huygens probe (provided by ESA) will be released to study the atmosphere of the satellite. On some of the remaining Titan flybys, a synthetic aperture radar (SAR) will be used to penetrate the obscuring atmosphere of Titan to take SAR images of the moon's surface.

1.2 Cassini Spacecraft

The Cassini spacecraft is approximately 6.6o meters (m) long, 4.o m in diameter, and has a mass allocation of 5,655 kilograms (kg) (2,523 for the spacecraft, and 3,132 for fuel). The spacecraft is subdivided into two major components - the orbiter and the Huygens probe. The orbiter delivers the Huygens probe to Saturn's moon Titan, then continues with the reconnaissance of Saturnian system. Cassini is somewhat unique for a planetary spacecraft in that it has no articulated platforms. The orbiter must orient itself in order to point any directional device, e.g. cameras or antennas.

The spacecraft contains six major engineering subsystems:

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2) **Command and Data Subsystem** (CDS)
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- spacecraft intercommunication
- telemetry packet collection
- on-board telemetry storage
- telemetry frame creation

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- attitude determination
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- thrust vector control
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1.3 Cassini Ground System (Telemetry)

The telemetry processing portion of the Cassini Ground System is based upon a system developed for multi-mission operations. l-his system was used with the Magellan, Mars Observer and Galileo spacecraft. Adaptations to this system to support Cassini were planned, but no architectural changes were to be made.

The multi-mission system was designed to support time-division-mu]tiplcxed (TDM) telemetry structures used on previous spacecraft programs such as Voyager, Galileo and Magellan. TDM telemetry is characterized by fixed-size telemetry frames, which contain measurements in a fixed order, with only very specific and limited variations (e.g., subcommutation). These frames are transmitted to the ground at only a small number of quantitized downlink rates. Each frame contains a synchronization pattern which provides the ground system a means for determining frame boundaries.

The resulting multi-mission system, used as the basis for the Cassini telemetry processing system, placed strict limits on the flexibility of telemetry production on the spacecraft. For example, these strictures prevented the use of variable size transfer frames, placed restrictions on telemetry packet size variability and measurement placement, did not allow time-tagging below the packet level, and did not easily handle multiple measurements in a single packet (supercommutation). Incorporating CCSDS telemetry design concepts, which encourage telemetry systems to be extremely flexible, in this environment presented many challenges.

2.0 Process for Incorporating CCSDS Standards

The incorporation of the CCSDS standards and philosophy into spacecraft telemetry systems at JPL is a continuing process which has progressed through many stages. The Mars Observer (MO) spacecraft was the first JPL spacecraft to use the CCSDS telemetry standards. Cassini is the second application, and while the Cassini telemetry design is constrained in many similar ways as the MO design, it also moves closer to implementing the CCSDS telemetry philosophy.

2.1 Difficulties with CCSDS Philosophy

The Cassini project decided to use the CCSDS standards for both the command and telemetry functions. However, full incorporation of the telemetry standards and philosophy held some challenges due to limitations of the Cassini mission, necessary characteristics of deep-space spacecraft, and differences between the CCSDS design concepts and the JPL culture.

The CCSDS telemetry standards provide a generic protocol for transferring observational data from the instrument to the end-user. This protocol was designed to facilitate "the acquisition and transmission of instrument data at a rate appropriate to the phenomenon being observed" [1]. This implies a design concept of demand-driven telemetry, where the telemetry producers determine the rate and size of the telemetry packets they produce, instead of a centralized packet collector. In addition, the CCSDS standards form a layered telemetry architecture, in which each layer depends on a set of well-defined functions provided by the neighboring layers. This design concept focuses on the telemetry functions to be performed, rather than the form of the telemetry system, and allows the physical design to be decoupled from the telemetry collection process.

The nature of the Cassini mission involves constraints which do not apply to other spacecraft, in particular the earth-orbiting spacecraft for which the CCSDS standards were primarily designed. These constraints include a limited downlink rate and constrained transmission opportunities, which in turn affect the design of the on-board data storage system.

The trajectory for the Cassini mission requires telemetry links at distances up to 10 AU over three antennas (1 high-gain, 2 low-gain), many times with a constrained attitude due to thermal limitations. The downlink rates for the first two years of the mission (with exception of one month-long period) range from 948 bits/see down to 20 bits/see. The limited downlink rate is an implicit requirement for efficient collection and transmission of the spacecraft telemetry. Because the CCSDS standards require considerable overhead (96 bits per telemetry packet, plus frame overhead), the average size of a Cassini telemetry packet is approximately 8000 bits. The large size results in a header overhead which is approximately 15% (considered to be a reasonable amount). However, at the low downlink rates during the early part of the mission, large packet sizes and large flame size (the Cassini frame size is fixed at 10112. bits) create problems with frame synchronization and measurement time-tagging. The large transfer frame size causes long intervals between reception of sync signals at low downlink rates, which increases the likelihood of a ground glitch or transmission channel noise causing an error which causes loss of the frame. Large packet sizes result in long periods between measurement updates (since supercommutated measurements cannot be uniquely time-tagged, each packet contains only one instance of a measurement).

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3.0 Resulting Capabilities

As a result of the implementation of the Cassini telemetry system, many of the capabilities envisioned by the CCSDS have been made possible within the mission and architectural constraints. Additionally, there have been some resulting benefits which increase the quality of the spacecraft telemetry.

While the Cassini spacecraft telemetry system began as a very limited implementation of the CCSDS standards and philosophies, the additional capabilities which were incorporated show an evolution toward the CCSDS design concepts. The STMS used by Cassini limit the number of telemetry producers at a given time and also dictate the amount of data each producer is allowed to produce. However, the zero-length packet concept allows a telemetry producer to vary the actual data volume within the limit set by the STM. In addition, changing the packet type or the usc of mini-packets gives telemetry producers a great deal of control over the telemetry produced. When these concepts are used effectively by the telemetry producer, the very efficient use of the limited telemetry resources can be accomplished.

In addition, the mini-packet concept provided a secondary benefit to the end-users of the spacecraft telemetry - greater measurement intercorrelation. One of the results of the large size of the Cassini telemetry packets is coarse indication of measurement sampling time. Even at high downlink rates, several seconds may pass between the collection of successive packets from an engineering subsystem. Because measurements are time-tagged with the packet time, it is difficult to determine exactly when a measurement changes values or when measurements within a packet were sampled with respect to one another. However, mini-packets can be used to sample measurements faster than once per packet. This allows for much better resolution of important measurements and better intercorrelation between measurements because the mini-packet time-tag applies to a smaller number of measurements.

4.0 Conclusions

"l-he CCSDS telemetry standards can be successfully applied to deep-space planetary missions, even in an environment of rigorous testing, design conservatism and biased culture. The Cassini telemetry system is an example of this, as it incorporates the CCSDS protocols and even with severe architectural constraints, is a flexible telemetry system not unlike the systems envisioned by the CCSDS designers. "l"his was accomplished by developing solutions which allowed variability in the spacecraft telemetry while remaining within the architectural! tenets of the design and the constraints of the mission. The Cassini design solutions, and the solutions used on the Mars Observer spacecraft, reflect an evolution in JPL spacecraft telemetry systems away from the traditional time-division-multiplexed systems toward systems which completely embrace the CCSDS standards and philosophy.

5.0 Acknowledgments

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of-l'ethnology, under a contract with the National Aeronautics and Space Administration. The implementation of the Cassini spacecraft telemetry system is based upon early work in the spacecraft information system done by Sandy Krasner.

6.0 References

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In order to provide packet producers with the capability to adjust the rate as well as the contents of telemetry packets, a concept known as "zero-length packets" (ZLPs) was introduced. ZLPs arc packets produced when an instrument has not collected enough information to provide a packet at the scheduled packet pickup. ZLPs arc identified by setting the length field in the packet header to an invalid (too small) value, but the actual size of the packet is the size defined for that producer in the current STM. ZLPs arc collected by the CDS, but arc not stored or downlinked. This allows instruments to usc only as much of their packet collection rate allocation in a given STM as needed. The packet collection rate allocation is usually set at the maximum data rate the instrument is allowed to produce in that STM, so the instruments can vary the effective output data rate without affecting the spacecraft telemet ry mode. This allows instruments with variable-ratio compression algorithms to use less downlink bandwidth and avoid storing packets which contain no data on the SSR. This capability, which gives the packet producers limited control over the volume of data produced, is a significant step toward allowing demand-driven telemetry.

3.0 Resulting Capabilities

As a result of the implementation of the Cassini telemetry system, many of the capabilities envisioned by the CCSDS have been made possible within the mission and architectural constraints. Additionally, there have been some resulting benefits which increase the quality of the spacecraft telemetry.

While the Cassini spacecraft telemetry system began as a very limited implementation of the CCSDS standards and philosophies, the additional capabilities which were incorporated show an evolution toward the CCSDS design concepts. The STMs used by Cassini limit the number of telemetry producers at a given time and also dictate the amount of data each producer is allowed to produce. However, the zero-length packet concept allows a telemetry producer to vary the actual data volume within the limit set by the STM. In addition, changing the packet type or the use of mini-packets gives telemetry producers a great deal of control over the telemetry produced. When these concepts are used effectively by the telemetry producer, the very efficient use of the limited telemetry resources can be accomplished.

in addition, the mini-packet concept provided a secondary benefit to the end-users of the spacecraft telemetry - greater measurement intercorrelation. One of the results of the large size of the Cassini telemetry packets is coarse indication of measurement sampling time. Even at high downlink rates, several seconds may pass between the collection of successive packets from an engineering subsystem. Because measurements arc time-tagged with the packet time, it is difficult to determine exactly when a measurement changes values or when measurements within a packet were sampled with respect to onc another. However, mini-packets can be used to sample measurements faster than once per packet. This allows for much better resolution of important measurements and better intercorrelation between measurements because the mini-packet time-tag applies to a smaller number of measurements.

4.0 Conclusions

‘1<hc CCSDS telemetry standards can be successfully applied to deep-space planetary missions, even in an environment of rigorous testing, design conservatism and biased culture. ‘l’he Cassini telemetry system is an example of this, as it incorporates the CCSDS protocols and even with severe architectural constraints, is a flexible telemetry system not unlike the systems envisioned by the CCSDS designers. This was accomplished by developing solutions which allowed variability in the spacecraft telemetry while remaining within the architectural tenets of the design and the constraints of the mission. The Cassini design solutions, and the solutions used on the Mars Observer spacecraft, reflect an evolution in JPL spacecraft telemetry systems away from the traditional time-division-multiplexed systems toward systems which completely embrace the CCSDS standards and philosophy.

5.o Acknowledgments

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6.0 References

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